

## INFRARED THERMOGRAPHY IN AID OF ELECTRIC VEHICLE DEVELOPMENT AND EXPLOITATION

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### ABSTRACT

This research aims to examine the effective and applicability of the infrared thermography approach in electric vehicle research, development and exploitation. Qualitative thermographic analysis was used for operational control and assess the state of the controlled object's temperature fields and display of temperature anomalies and quantitative analysis to determine the numerical values of the characteristics of the temperature fields of the controlled objects detected defects. Mainly are analysed the thermographic results used as a criterion during the study of the traction battery characteristics. Brief discussion is also given of the results of thermographic measurements of the electric motor, coupe and solar panel of an experimental electric vehicle-lab.

**KEYWORDS:** Energy Efficiency, Electric Vehicles, Batteries, Infrared Thermography, Nondestructive Evaluation

### INTRODUCTION

The electric industry is the basis of so-called "green industry." On the other hand, important factors in determining a "new start" of the electric car industry are rising fuel prices and limited resources, and environmental damage [1, 2, 3, 4]. The relationship between the final and the primary energy consumption indicates the energy efficiency. In internal combustion engines, energy efficiency is worth 16-29%, while in electric vehicles (EVs) is between 26-43%, according to an analysis of the European Union.

In recent years, infrared thermography more successfully established itself as a powerful tool for diagnosis and maintenance of equipments from various engineering fields. By detecting anomalies often invisible to the human eye, infrared thermography demonstrates the need for corrective action before the relevant electrical or mechanical devices to move beyond their rated performance. The widespread use of the opportunities offered by infrared thermography is due to reliable information that it provides about the technical equipment.

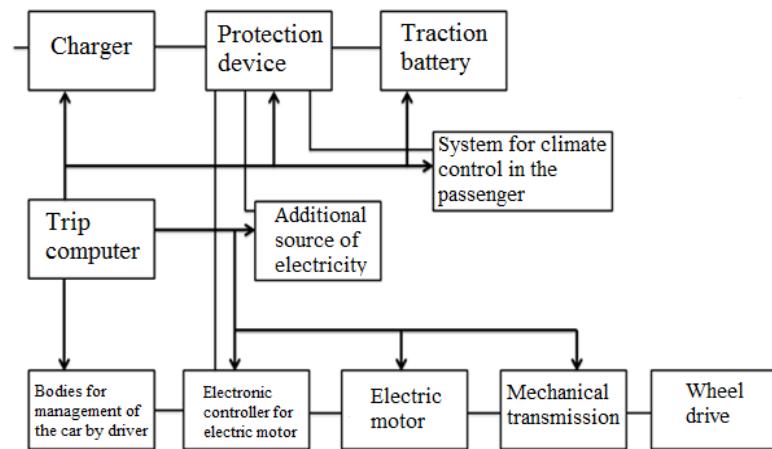
This article discusses the application of the thermographic method mainly for diagnosing traction batteries. Additionally and briefly is discussed the applicability of the nondestructive thermographic evaluation approach for photovoltaic system and engine and coupe of an experimental electric car. The aim of this project is to measure the distribution of heat in the assemblies and components for electric car by using the thermography approach for quantification and characterization of important parameters and characteristics.

### THERMAL SURVEY IN THE DEVELOPMENT AND EXPLOITATION OF ELECTRIC VEHICLES

Thermographic observation is made of separate parts of a classic electric vehicle developed by a team of VTU "T. Kableshkov" led by Prof. I. Milenov [5]. The car chosen for reconstruction, is a brand Renault Kangoo model as the coupe is retrofitted. On the roof is mounted polycrystalline photovoltaic (PV) panel with a capacity of about 200 W. The energy

generated by the PV charges 12V car battery that powers: headlights, turn signals, wipers, hydraulics for cornering, vacuum brake booster, etc.

Basic units and assemblies of the electric vehicle are shown in Figure1.



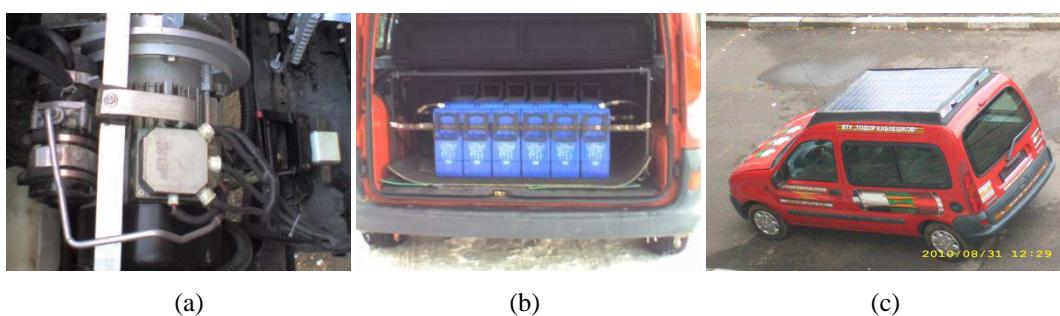
**Figure 1: Block Diagram of an EV**

The traction battery pack is composed of six pieces of lead type batteries with immobilized electrolyte ML220C (gel) that is unattended. They do not emit harmful gases and have a special structure that allows deep discharge.

The EV is designed as a laboratory and allows the implementation of variety of measurements and tests. So while driving in real traffic conditions a large number of parameters predetermined by the test can be measured and recorded in the computer memory. The electric car has passed all tests, and is in regular exploitation.

Thermographic measurements were conducted during development, in the static tests as well as tests in real working conditions.

On Figure 2 the appearance (with an open front and back cover) of the EV, and a rooftop solar panel is visible, appearing as a key element of the generating system are shown [6].



**Figure 2: Separate Views of the Tested EV**

Additional thermocouples are used for temperature measurement. The temperature measurements from the thermocouples are used to calibrate the infrared camera's results.

Three sets of characteristics are given when used infrared instruments in non-contact temperature measurements are: the surface of the subject; transmission medium between the subject and tool, and measuring tool.

Emitting power is a very important characteristic of the object's surface and it should generally be known in order to make accurate non-contact temperature measurements.

### Performed Thermal Control Includes

- Analysis of engineering and technological documentation;
- Determination quantitative temperature on the controlled object surface;
- Identification of the additional features of the surface condition and the environment;
- Qualitative and quantitative analysis of the temperature fields on the studied surface;
- Emergence of new zones with anomalous temperature determined by the presence of defects in the controlled object;
- Calculation based on measurements performed for the technological parameters of the objects and their comparison with the standard values;
- Defining the parameters of a defect.

The processing results from the thermal control consists in qualitative and quantitative analysis of temperature fields of the studied subject and other auxiliary parameters related to the subject, inspecting equipment, and environmental and special feature in conducting the heat control.

There are of course some disadvantages of the thermography approach. Major obstacles create the impermanence of emissivity coefficient, which is highly dependent on the condition and location of the surface of the controlled object. To reduce the variation of emissivity coefficient is held preparing the surface quality. The quality have to be the same for all controlled sites or the controlled surface coatings are applied so that the emissivity coefficient to be closer to 1.

## EXPERIMENTAL RESULTS

The EVs use large number of electric battery elements (battery cells) [7]. And continuous monitoring and tracking of their potential degradation provides valuable information for producers and consumers.

Thermographic measurements are performed by using Flir ThermaCam SC640 with additional 45° and close-up lenses.

The specific power of the battery (battery pack) directly affects the dynamic properties of the EV. Durability, lifetime and cost of battery life also affect the cost and reliability of EV. It is therefore essential any parameter that affects the battery to be optimized. One such parameter is the change in temperature of the battery pack.

The electrical balance between different modules in the pack has got an important influence on the operating temperature of the battery. The efficiency of the battery pack depends on the performance of individual modules. If the temperature of the cells and modules in the pack is different, each module will be charged/discharged during each cycle a little different. After a few cycles, this can lead to misbalancing of the individual modules and degradation in the performance of the battery pack.

For control and diagnosis of such a system can be successfully used infrared thermography. The advantages of this method are its ability to remotely and non-destructive measurement of the heat distribution over a large area (it can cover not only the individual modules, but the whole pack) without suspending the operation of the object.

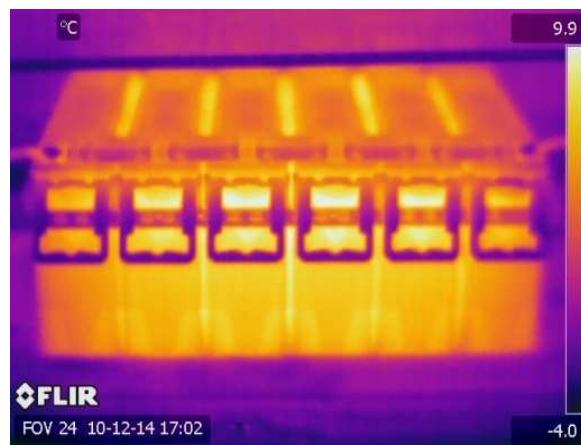
The heat in the battery cell is generated through two mechanisms: (1) the effect of Joule (or "resistive" heating) caused by the electricity current transfer and (2) change in entropy of the electrochemical reaction. The ratio of these mechanisms is different in different types of batteries. Heat generation due to loss of electrical power, for example can lead to some electrochemical couples to recharge of a fully charged cell. The rate of heat generation in a cell can be calculated from [...].

$$Q = -I [T (dE/dT)] + I (E - V) \quad (1)$$

where:  $Q$  – heat generation rate (W);  $I$  – current (A);  $I > 0$  for discharge and  $I < 0$  for charge;  $T$  – temperature (K);  $dE/dT$  – temperature coefficient (V/K);  $E$  – equilibrium cell voltage or open-circuit potential (V);  $V$  – cell voltage or cell potential (V).

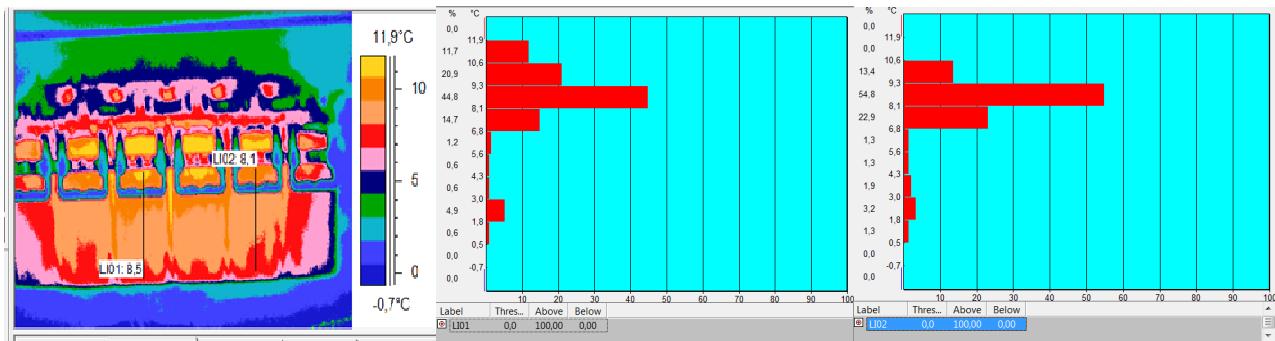
With the help of software Researcher Professional 2.9 the evenness of the heat distribution on the surface of different areas is studied and is defined hot areas of the battery pack.

Thermograms are captured at various mileage and EV load. The aim is to examine evenness of the heat distribution on the surface of individual batteries in the pack. On the Figure 3 such a thermogram is shown.



**Figure 3: Thermogram of Tested Traction Battery Pack**

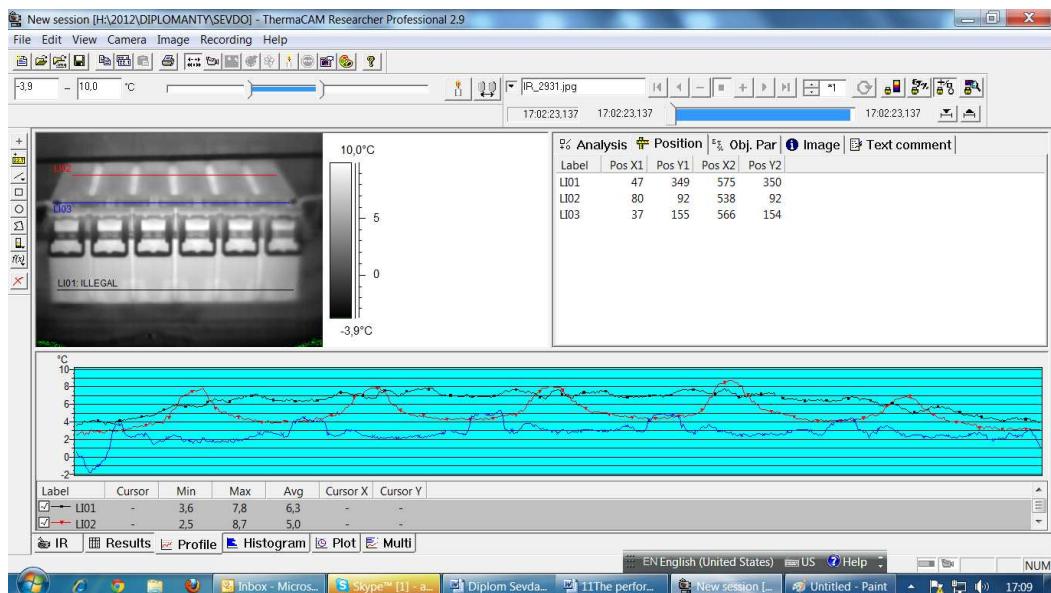
Figure 4 presents an thermal analysis of a battery pack. Two batteries' histograms can be compared. It can be seen that the difference in the average surface temperature between lines 1 and 2 is  $0.4^{\circ}\text{C}$ . The temperature difference between these two batteries and the batteries' surface temperature located at the two ends of the pack. exceeds  $3^{\circ}\text{C}$ .



**Figure 4: Analysis of the Temperature Difference between Two Batteries of a Pack**

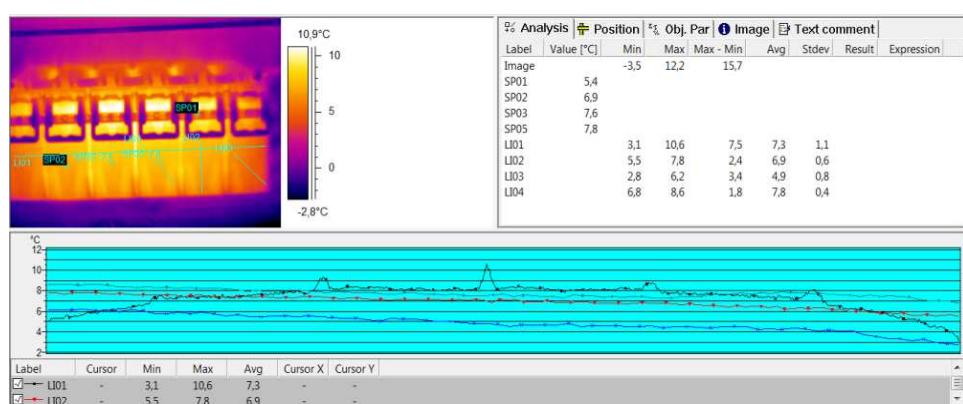
On Figure 5 a thermogram of a traction battery after a run of 50 km in urban conditions is shown and the surface temperature profiles are also measured.

The temperature differences in different areas of the battery pack are clearly detected.



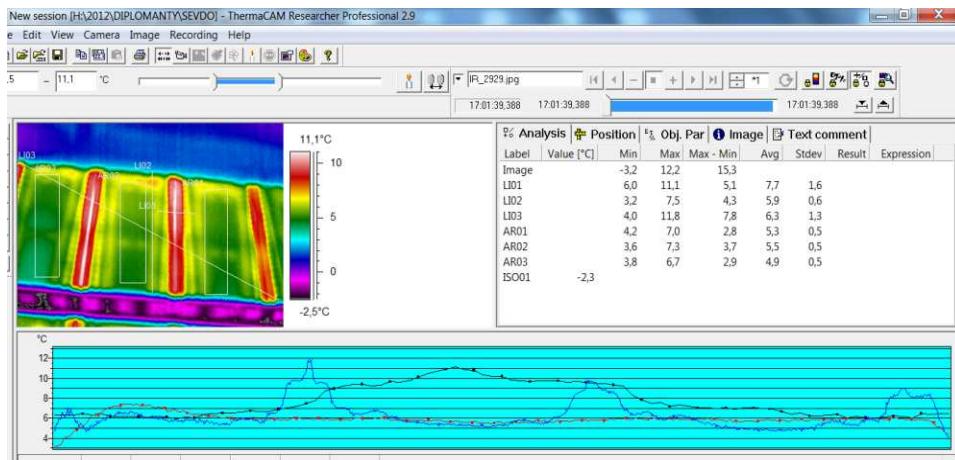
**Figure 5: Analysis of the Temperature Distribution of the Traction Battery after Run of 50 km**

The air gap between batteries in the pack leads to decrease the heat convection. This can lead to uneven heat distribution of the module and appearing of some critical areas. This situation can be seen in Figure 6.



**Figure 6: Analysis of the Air Gap between Batteries of the Pack**

On the Figure 7 an uneven heat distribution on the surface of a battery pack and between separate batteries of the same pack is shown.

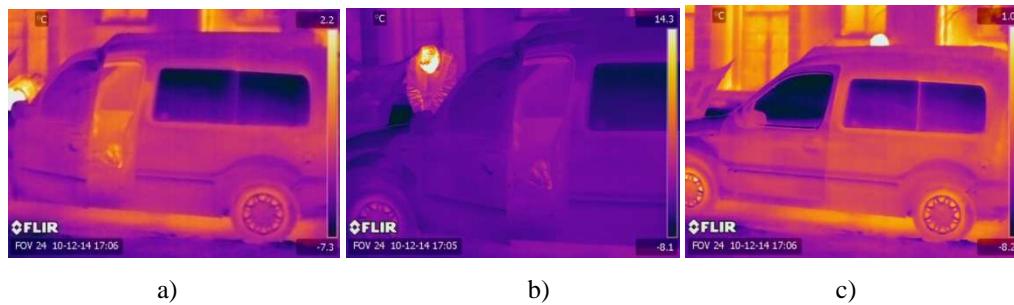


**Figure 7: Analysis of the Uneven Heat Distribution on the Battery Surface**

It had been examined the main characteristics of infrared images to check their usefulness for a rapid and non-aggressive way for accurately sorting the information from traction batteries for electric vehicles. Infrared imaging system effectively indicates the order of selected areas on level of the cell, the entire cell, module or pack. Termograms of the battery passing through different states or thermal cycling are recorded. The maximum reached temperatures and hot zones of the cells are detected by infrared inspection.

Thermographic measurements were carried out of the vehicle coupe to determine the uniformity of distribution and the thermal comfort in it. Figure 8 shows termograms of the vehicle's coupe after different mileage.

From the photos of EV (fig.8a, b) with open door is observed difference between internal and external temperatures. From thermogram in Fig. 8c can be seen the uniformity of heat distribution on the outside of the coupe. On the figure 8a, b the significantly warmer zone of the inside of the coupe can be seen. This shows that thermography can be successfully used for assessing the quality of the vehicle's coupe compaction and comfort. Such studies were not aimed in this project so accurate assessments of the audit results of the coupe are not performed.



**Figure 8: Thermograms of the Inside Parts of the Coupe**

Maximum permissible loads such as maximum power, speed, electric heating, etc. are carried out during the tests of the EV.

Testing was also conducted in a testing laboratory as well as in urban and extra-urban traffic.

Additional studies were performed for thermographic evaluation of the heating of the motor at different load conditions [8]. On the Figure 9 can be seen different thermograms of the EV electric motor with their heat zones. The detailed results and optimistic assessments also provide perspectives on the use of thermography approach in these studies.



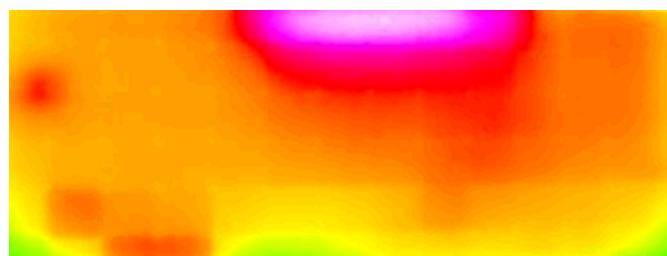
**Figure 9: Thermograms Showing the Surface Temperature Distribution after Different Load**

A thermographic study of the photovoltaic panel was also performed. When the solar cells do not work or do not produce energy as they are not shine on by sunlight can sometimes invert their polarity.

They behave more like a field of interruption rather than a generator and this can lead to an increase in energy conversion into heat.

This state of the cell can easily be detected with thermal imaging cameras. The most favorable condition for detecting problems in this case is when the module provides the most power (Figure 10). Under such conditions, cells can quickly reach temperatures over 100 °C degrees.

Defects encountered in working photovoltaic panels can be quickly diagnosed through thermovision infrared cameras. Such defects can be: defective contact connections and short circuits, penetrated moisture, dirt, cracks in cells or glass module, not connected or no working modules, reduced efficiency of the module



**Figure 10: Thermogram of Defected Photovoltaic Panel**

## CONCLUSIONS

From the termogram it can be estimated predominant amount of heat generated by the cell during charge and discharge. This action can prevent the recharge of a loaded cell.

The heat control is applied to identify defects and determine their parameters to assess the quality and conformity of controlled objects with requirements of normative documents. Available additional connection cables can lead to increased the heat of separate modules. Thermographic testing of battery packs helps to study the temperature range and to choice an optimal options for maintaining effective heat mode (using active or passive thermal management approaches or their combination). The thermographic testing of battery packs helps to study the temperature range and choice optimal options for maintaining effective heat mode (using active or passive thermal management approaches or their combination). The effect of temperature on examined battery charging was studied and found that the charge acceptance

rates dropped as the temperature dropped, especially below 0°C. The performance and life of the EV battery packs has been evaluated and was found that the temperature gradient between modules reduces overall pack capacity.

Providing accurate, reliable and repeatable temperature measurement of the EVs is the basis for successful use of thermography as a tool to diagnose their condition.

## ACKNOWLEDGEMENTS

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